Thresholds of Disturbance:

Land Management Effects on Vegetation and Nitrogen Dynamics

CS-1114E-00

Beverly Collins

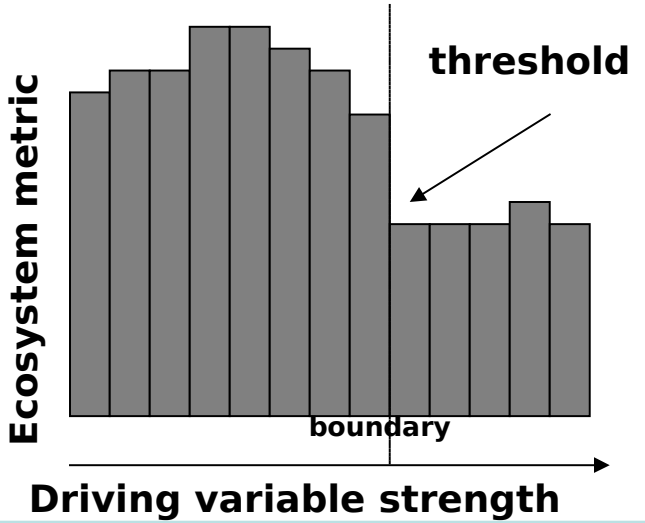
Savannah River Ecology Laboratory

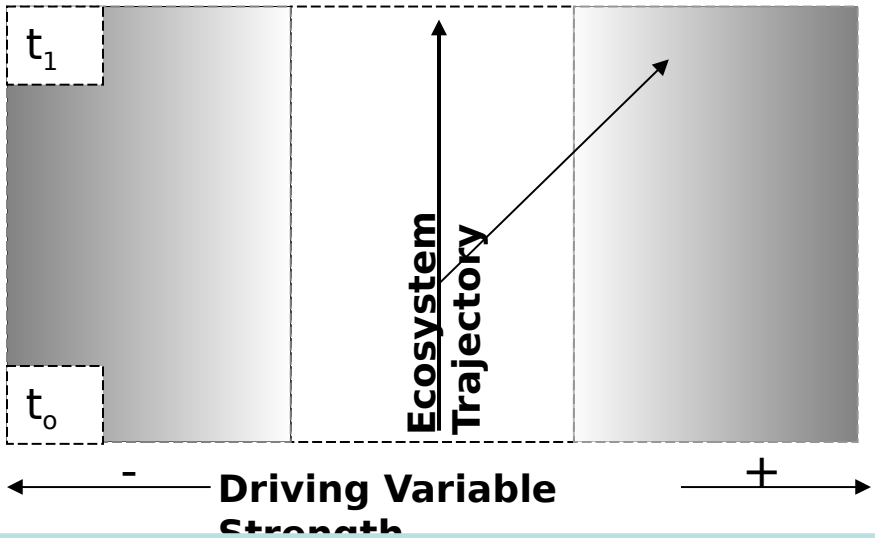
BRIEF TO THE TECHNICAL ADVISORY COMMITTEE

OCTOBER, 2002

Ecological Thresholds

A “sudden change in any property of an ecological system as a consequence of smooth and continuous change in an independent variable.” (Muradian, 2001)





A deflection of system response (or an ecological discontinuity) following a stimulus or stressor (Romme et al., 1998)

SREL Research Objectives

To evaluate the ecological effects of military training and forest management toward longleaf pine at Ft. Benning, to determine if there are thresholds beyond which upland ecosystems cannot sustain the combined effects of these land uses.

Research Hypothesis and Approach

Initial hypothesis

underlying soil type partly determines forest composition and dynamics, modifies the effects of military training and forest management, and influences the disturbance threshold for sustainability

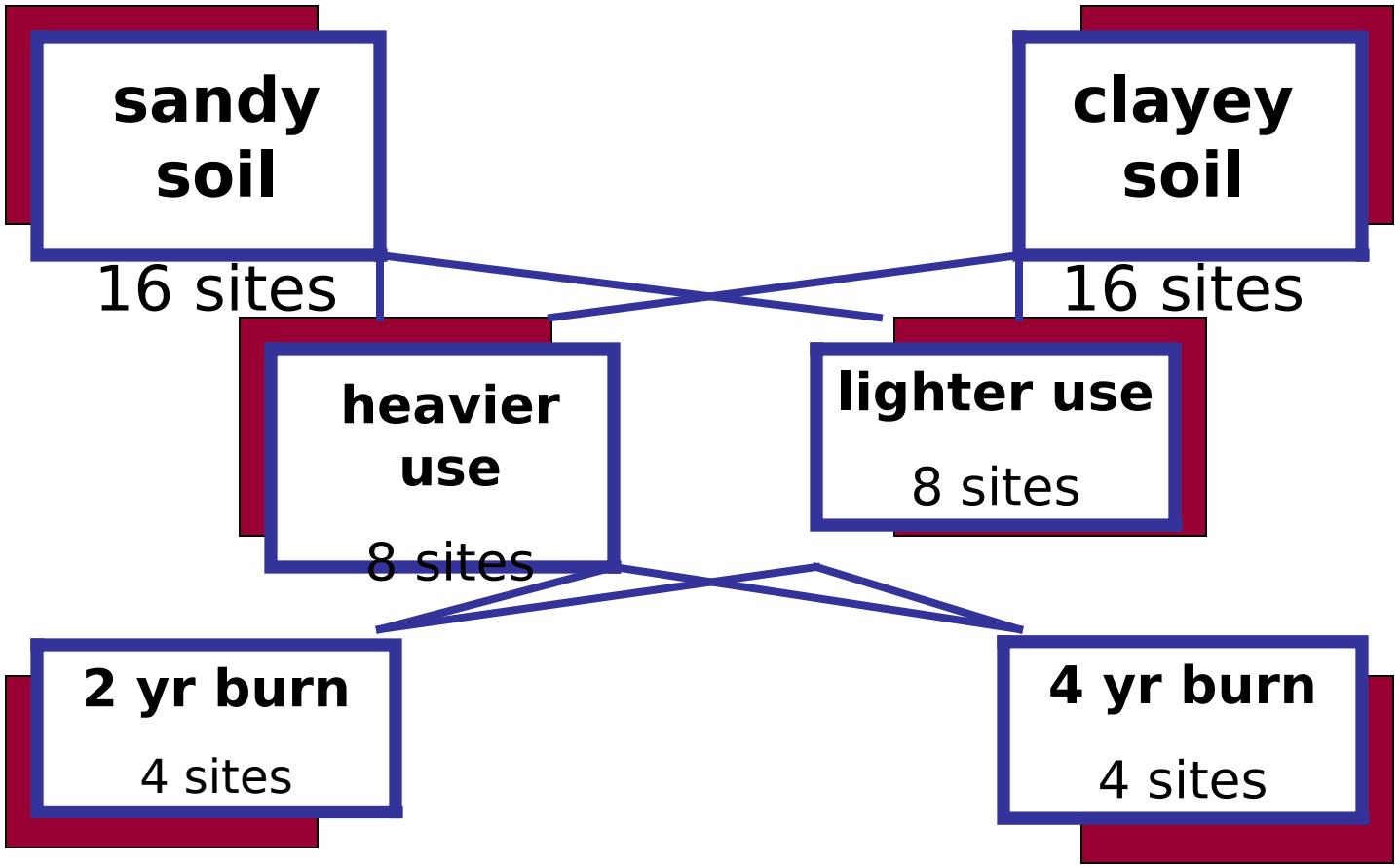
Experimental approach

- **Sites with sandy vs. clayey soil, combinations of forest management for longleaf pine: (2 yr vs. 4 yr burn cycle [applied treatments]; a range of time since thinning over sites)**
  - **lighter vs. heavier military training**

Note: all sites were burned spring, 2000 (year 1). Burn treatments (2 yr burns) applied winter-spring, 2002

metrics

biogeochemical cycling (N,C), vegetation composition and structure



Sites within each burn treatment/military use/soil texture category included a range of time-since-thinning

DESIGN

Procedures

I. Sites (32) chosen from a set of sites that were prescribe-burned winter-spring, 2000. Half of these sites (2-yr burn treatment) will be re-burned winter-spring, 2002. The other 16 sites (4-yr burn treatment) will have burning delayed until winter-spring 2004. Thus, the experiment will include two 2-yr burn cycles and one 4-yr cycle.

II. Surveys conducted in year 1 (2000) to determine the baseline condition of all sites.

III. In year 2 , sites sampled and field protocols established to monitor responses to the accelerated/delayed burns.

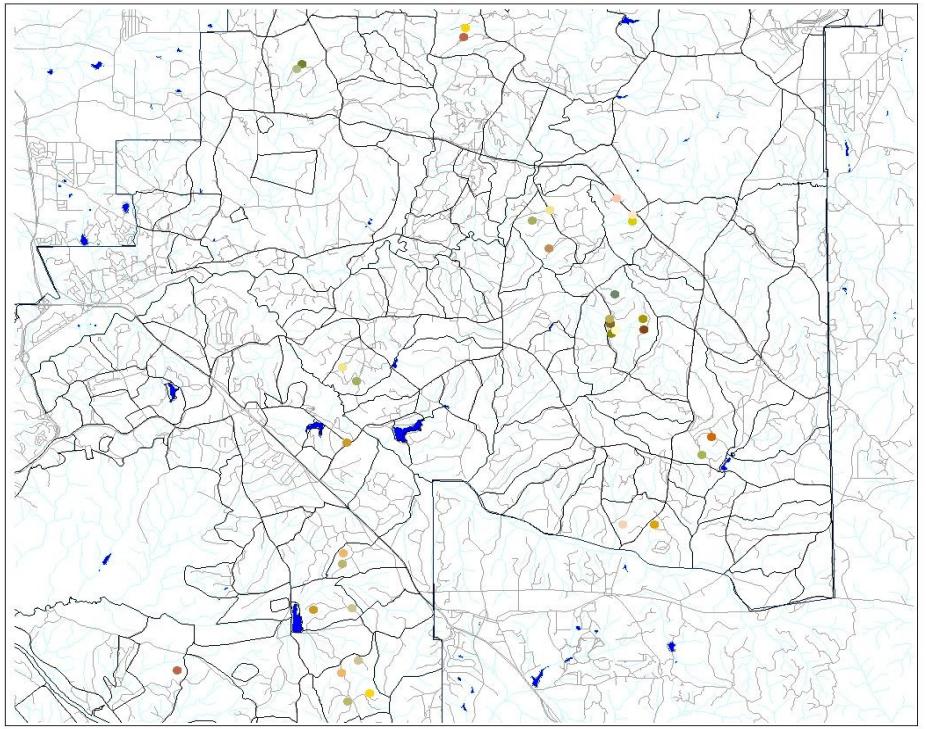
IV. Two-year burn sites burned prior to summer, year 3 (2002). All sites monitored to determine initial responses to fire and compare between burned and unburned sites over the incorporated range of thinning, military use, and soil texture.

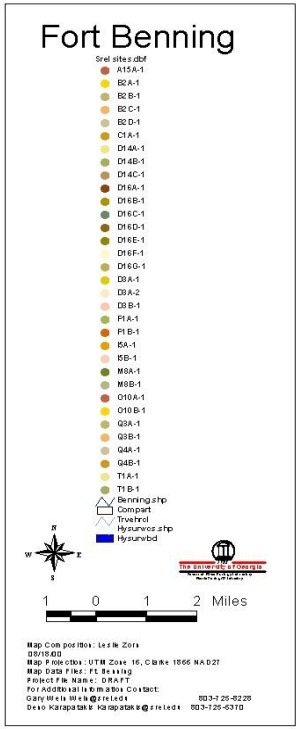
V. In year 4 (2003), burned and unburned sites monitored to compare second (burned) or fourth (unburned) season responses across the range of site types.

VI. All sites burned prior to year 5 (2004). All sites monitored to evaluate thresholds of sustainability in more (2-yr) and less (4-yr) frequently burned sites that differ in forest thinning, soil texture, and military

Year 1 (2000)

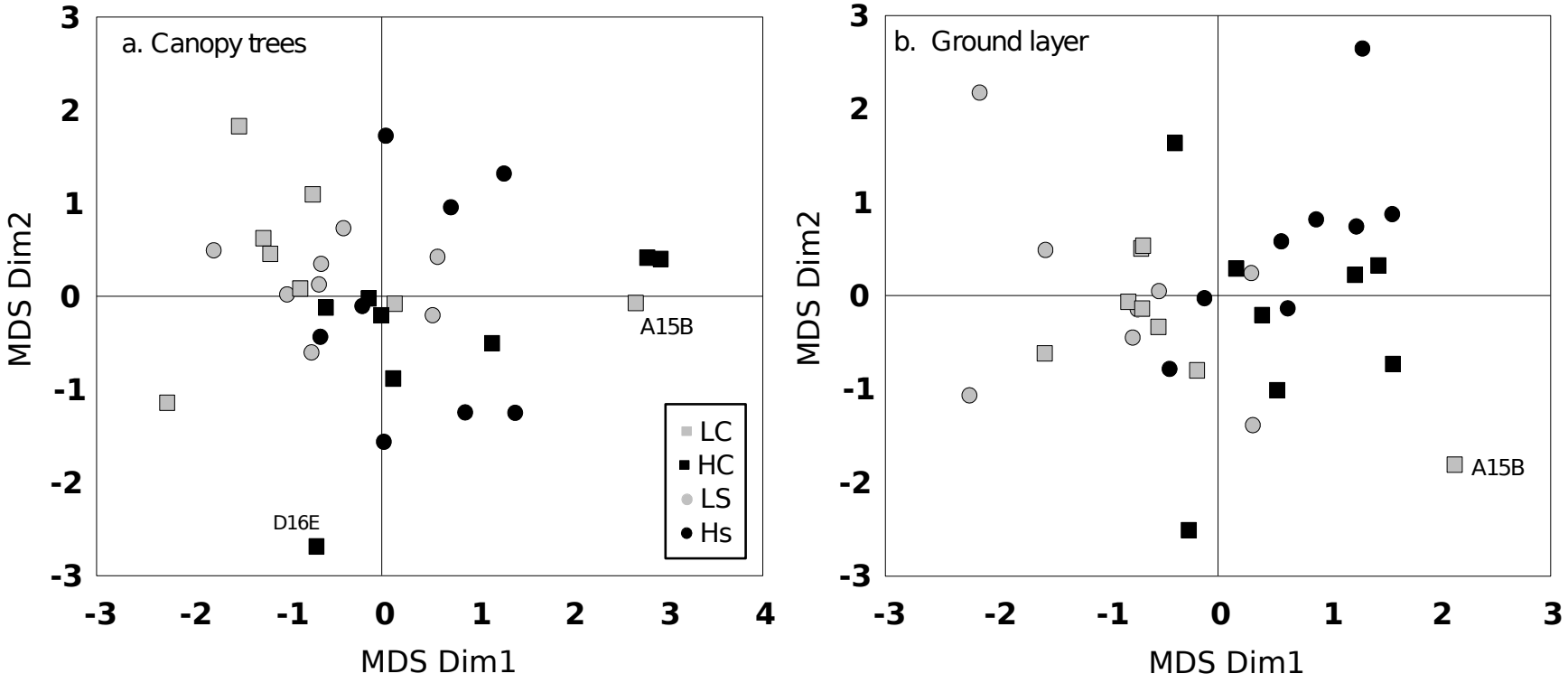
sites selected (3-5/00)





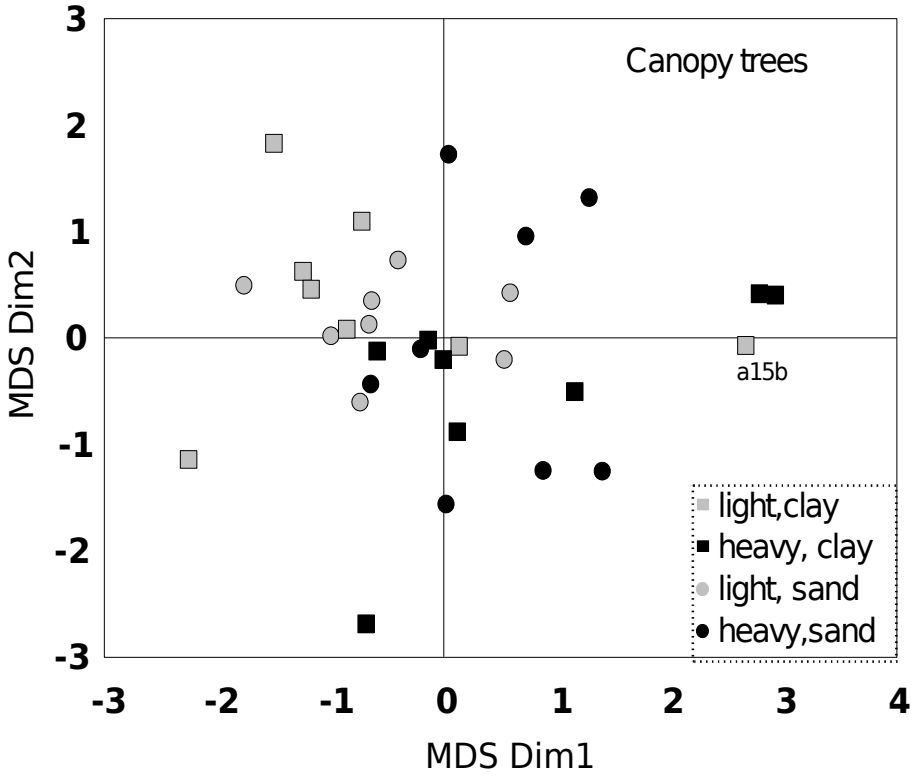
Baseline surveys: vegetation survey

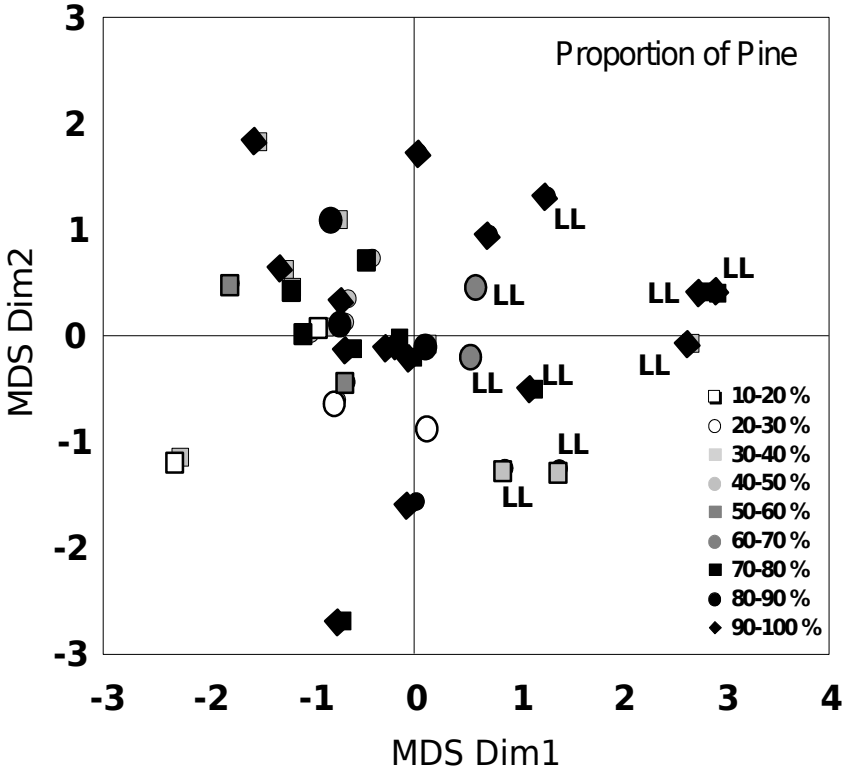
(6-8/00)



Differences in past land use over the 32 sites could have resulted in different initial conditions among the sites. Ordination, which arrays sites by vegetation similarity, indicates that initial canopy and ground layer composition of the 32 sandy (S) and clayey (C) sites was related to intensity of land use. Sites in heavier military training areas (H) fall together to the right in each graph; A15 burns frequently.

vegetation survey (6-8/00)





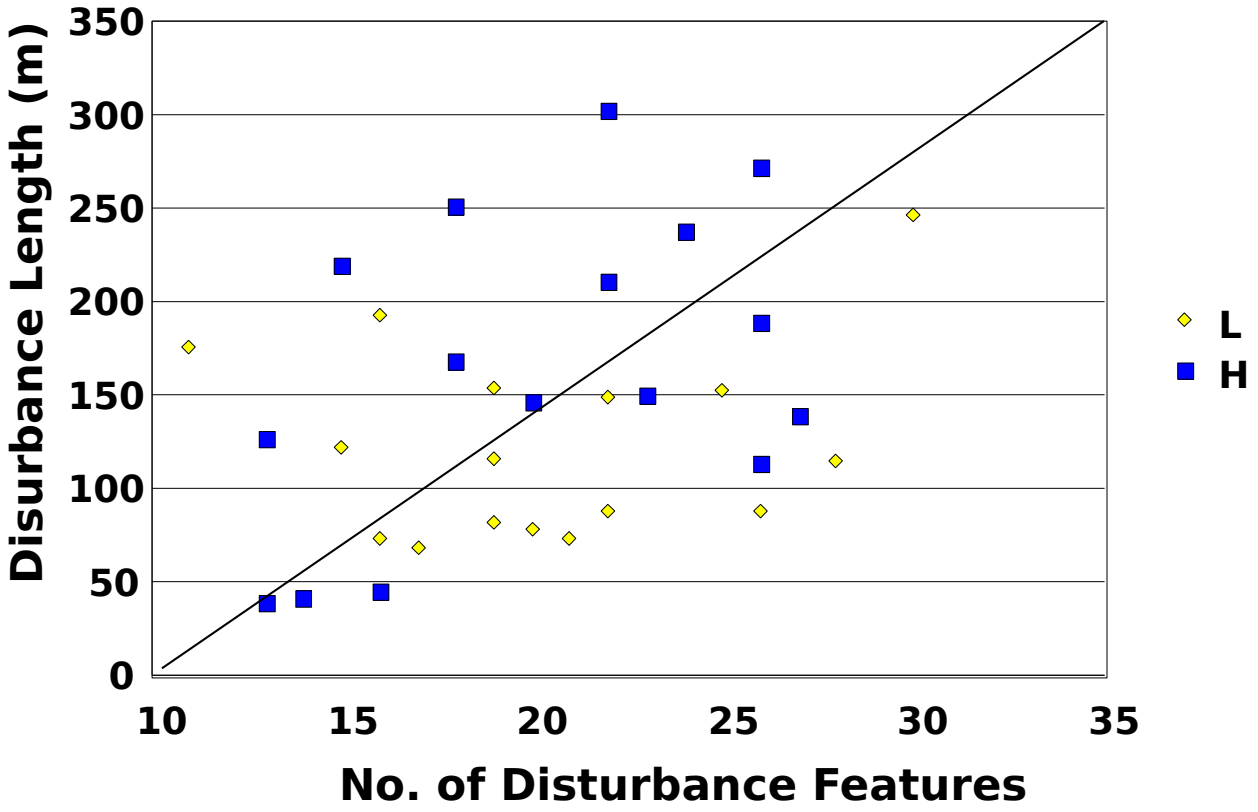
Canopy tree ordination reflected the proportion of pine in the canopy. Sites with a significant amount of longleaf pine (LL) fall together to the right. These include sites in heavier military use compartments and the frequently burned A15. Is there a threshold of land use intensity for longleaf pine?

disturbance survey (9-10/00)

Disturbance features were surveyed by line-intercept in a 400 m block centered on each 1 ha site to determine if pre-existing land use left features that could be quantified and related to initial site characteristics (vegetation, soil biogeochemistry).

- at least 4 different types of disturbance features were found in each site; 7 % to 50 % of sampled area was disturbed
- disturbance features ranged from small (treefalls, depressions) through large (canopy gaps, bare areas, clearcuts)
- remnant roads were the most common disturb
they occupied 14 % of the total disturbed area

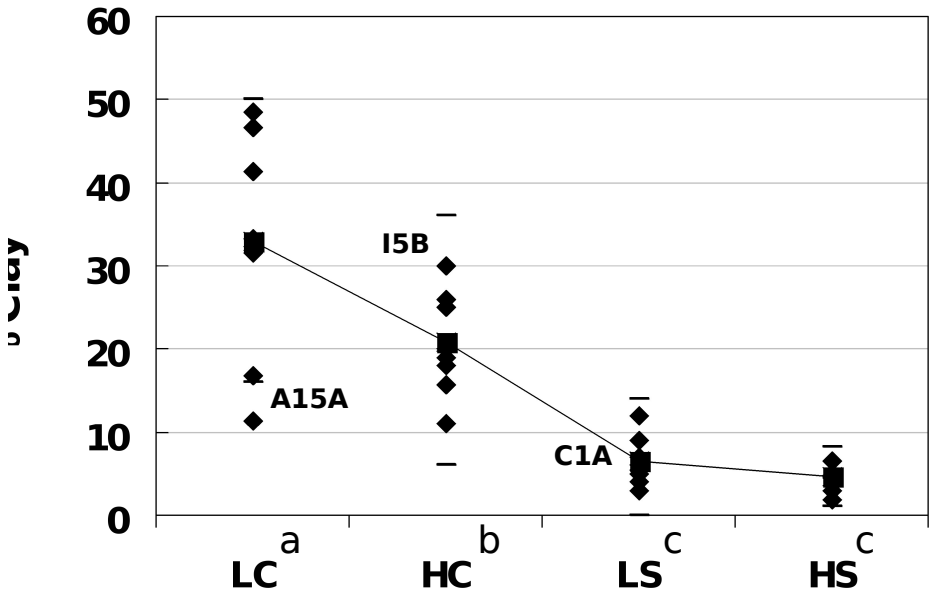
disturbance survey (9-10/00)



Sites with heavier military use did not necessarily have more disturbance features than lighter use sites (H sites are not grouped to the right on the x-axis), but tended to have a greater amount of disturbance (H sites tend to fall above the diagonal line)

baseline soil texture analyses (9/00-2/01)

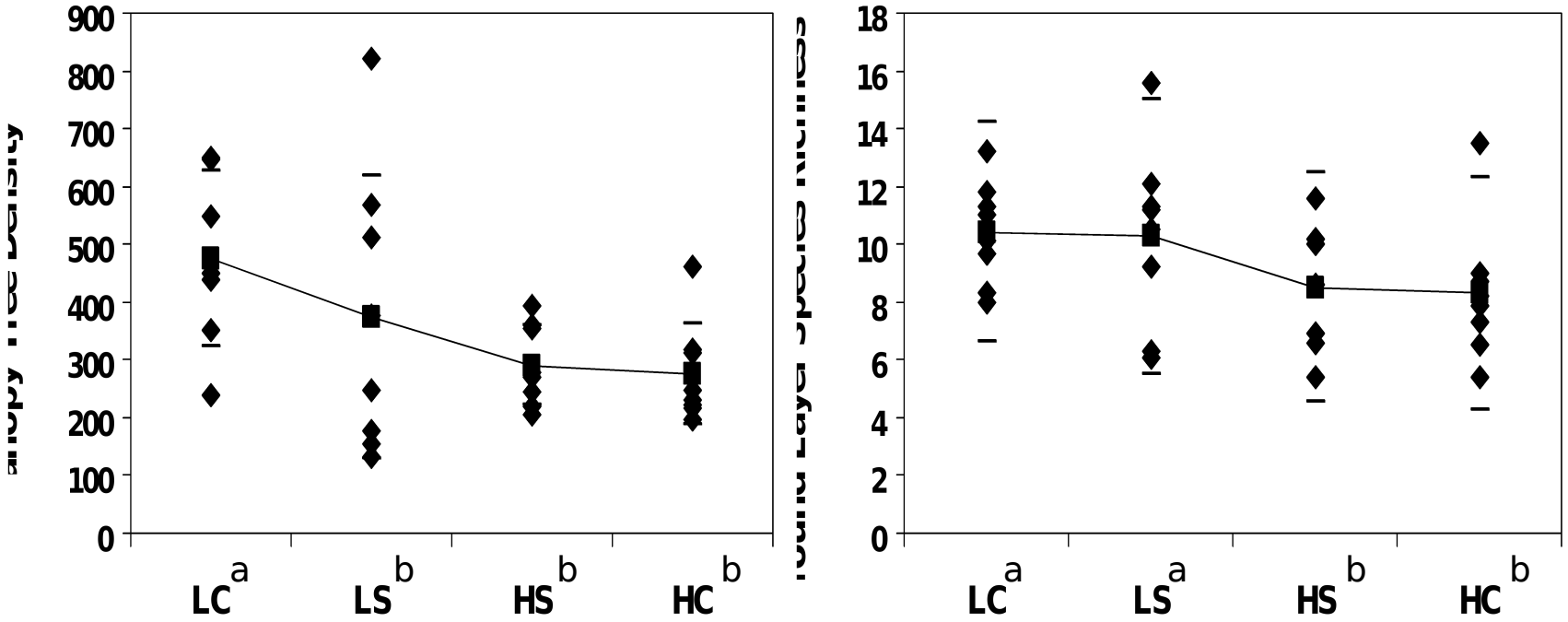
Soil samples (9/site) were collected from each site and analyzed for soil texture for two purposes: 1) to verify that sites (chosen using soil survey maps) were categorized accurately and 2) to determine if existing (pre-experimental) site characteristics (vegetation, biogeochemistry) were related to soil texture.



soil texture (% clay) was more uniform in sandy sites (3 - 12 % clay) than in clayey sites (11 - 50 % clay)

Graph shows mean and standard deviation for military training/soil texture category and means for all sites within the category. Line connecting means is only to improve readability.

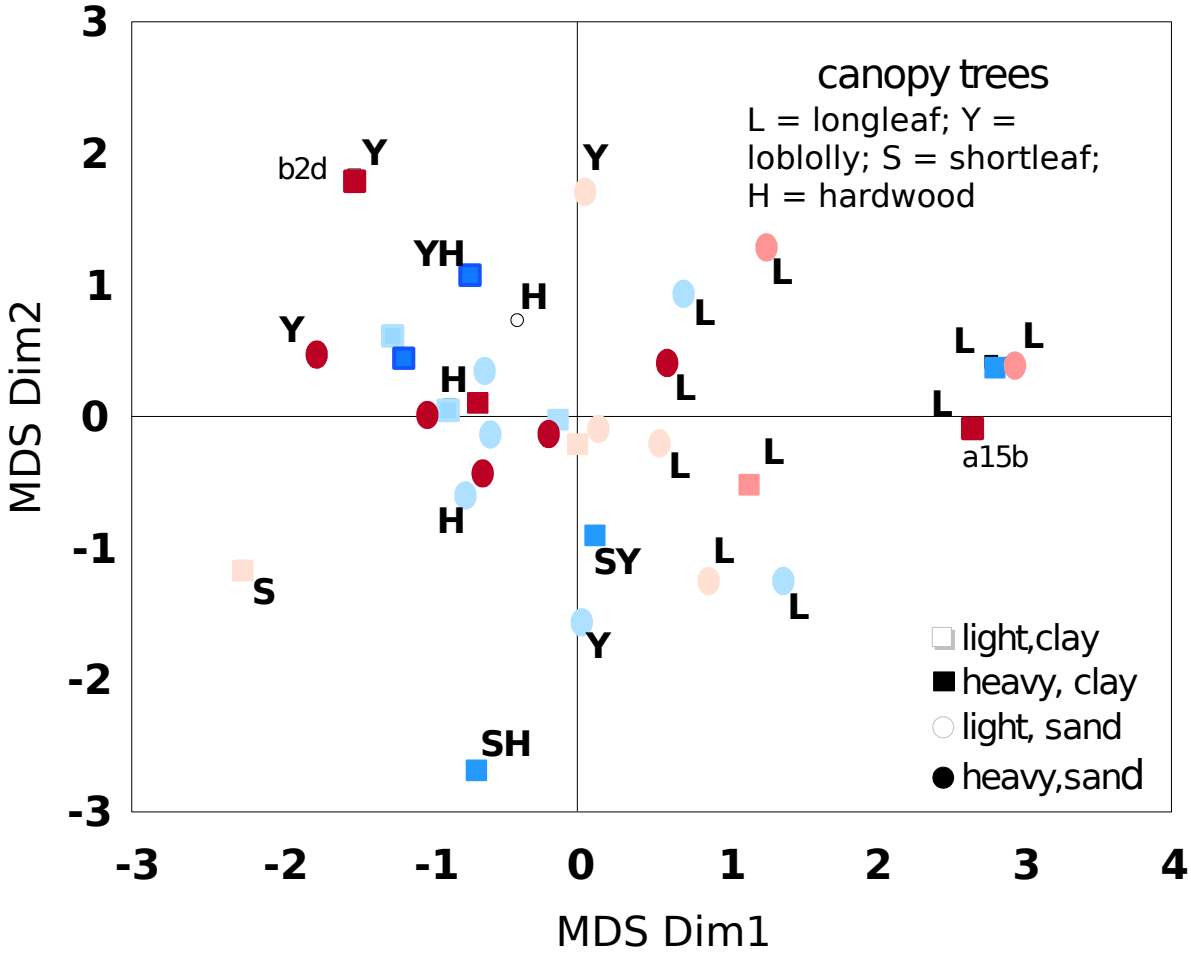
Did soil texture or military use affect vegetation?



Graphs show the soil texture/military use category mean (squares), the mean of each site in the category (diamonds), and the standard deviation (lines). Canopy tree density (no/ha) was higher in clayey sites (C) with lighter (L) military use. Ground layer species richness (no/ha) was higher in both clayey and sandy (S) sites in lighter military use compartments. These results suggest both soil quality and military training intensity affected existing vegetation abundance and diversity.

Did past burning affect vegetation?

SREL sites were overlaid on digitized fire maps to determine if differences in recent fire history (since 1980) were related to initial vegetation differences among the sites



Burn frequency, indicated by colors from dark blue (2/20 yr) to dark red (6/20 yr), overlain on canopy tree ordination; letters indicate dominant canopy species.

- **longleaf (L) in sites with either heavier military use** or **more frequent burns**
- **hardwood (H) sites infrequently burn; mostly lighter military use**

fire frequency, military use, and ground layer vegetation

loblolly pine

sweet gum, oaks, sassafras

loblolly pine

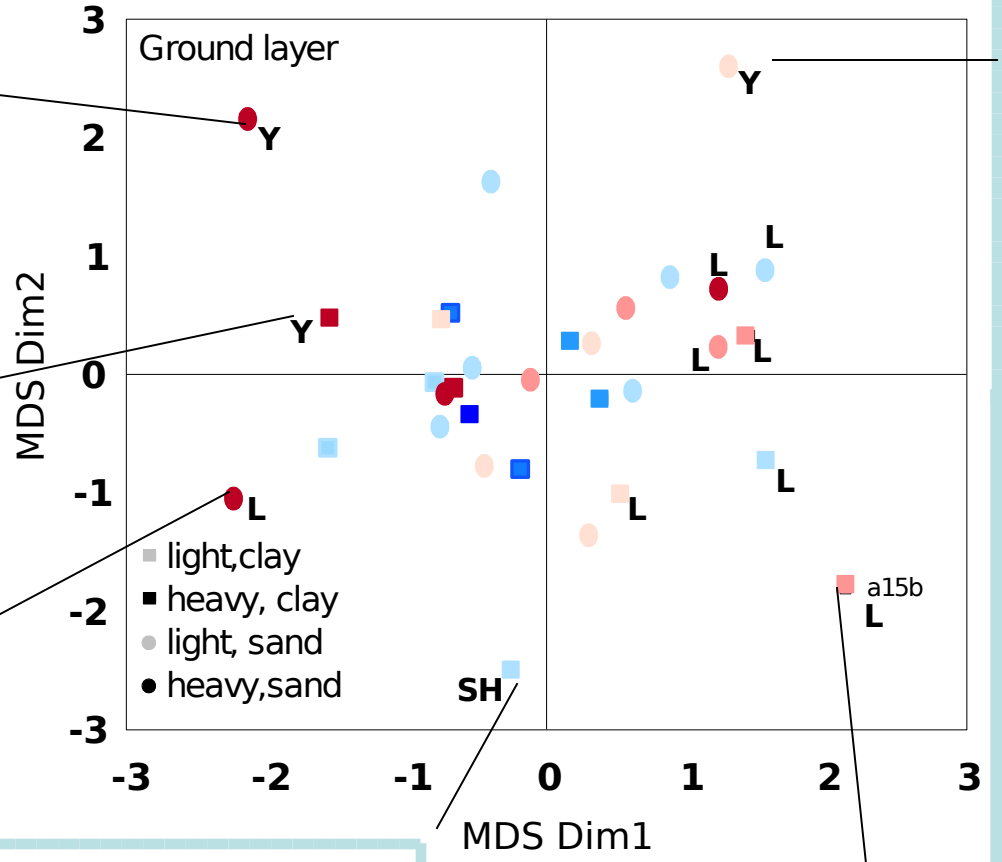
sweet gum

longleaf pine

sweet gum, *Ilex glabra*

shortleaf pine, hardwoods

bracken fern, *Smilax* spp, sweet gum, loblolly, black gum



loblolly pine

Heterotheca graminifolia, sumac, poison ivy, oak seedlings

longleaf pine

grasses, bracken

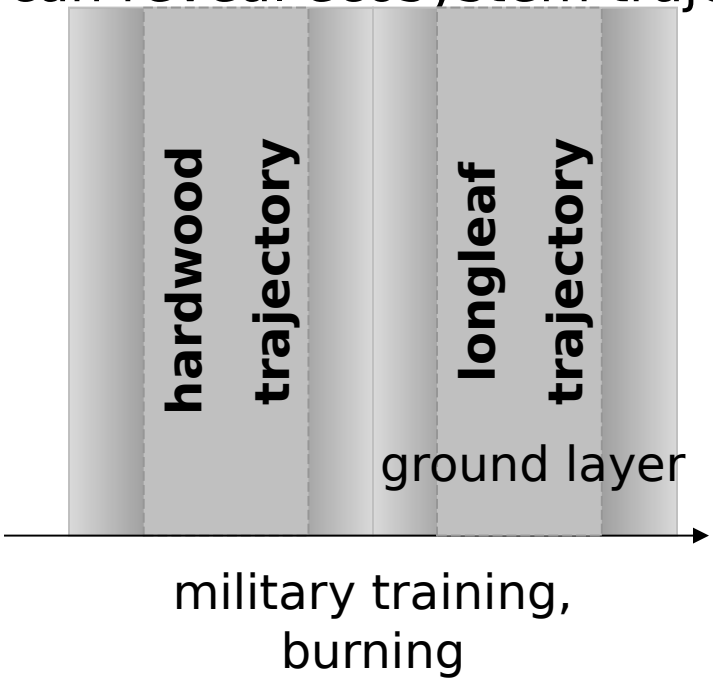
- sites with unique species composition tend to have burned ≥ 4 times since 1980 or are in heavier military use compartments
- these sites are dominated by open-site, early successional, or fire-tolerant

Summary: initial site conditions

- The 32 upland sites range from sandhills scrub oak-pine vegetation to shortleaf pine-hardwood or oak-hickory dominated forests.
  - Disturbances associated with mechanized military training and forestry practices (burning) have favored pine dominance, and maintained open-site, successional or fire-tolerant species in the understory.
  - Tree density and species diversity are influenced by soil texture, with greater tree density and understory diversity in sites with clayey soil.
- Sites in training compartments open to tracked vehicles have a greater abundance of disturbar[illegible]ites with dismounted infar[illegible]

Initial site conditions and thresholds of sustainability

Initial site conditions provide information about thresholds of sustainability for past land use. Comparisons of metrics (vegetation composition, diversity; biogeochemistry) among sites that differ in military training intensity, forest management can reveal ecosystem trajectory.



- pine (longleaf) canopy sustainable with heavier military use or frequent (≤ 3 yr) burns
- more frequent burns (≤2 yr) can promote open-site, successional understory with little regeneration of canopy species (beyond threshold of sustainability?)

Thresholds may be difficult to identify in systems with multiple driving factors without explicit tests of the factors individually and in combination.

Year 2 (2001)

Sites were sampled and field protocols established to monitor responses to the accelerated/delayed burns

- Oak/pine seedlings introduced (1-3/01)
- Monitoring equipment/sensors deployed (1-4/01)
  - soil temperature sensors
  - soil moisture probes
  - air temperature sensors
  - litter decomposition bags
  - litter/seed fall traps
  - plant root simulator probes
- Stable isotope (15N) litter deployed (pilot project) (3-4/01)
- Vegetation re-surveyed (6-8/01)
  - canopy photos (6-8/01)
- Naturally established seedlings marked (6-9/01)
- Field samples collected for biogeochemistry (C, N) (5-7/01)

Sites will be resampled or sensors left in place through the end of the experiment (2004) to capture responses over the two 2-yr burn or one 4-yr burn cycle.

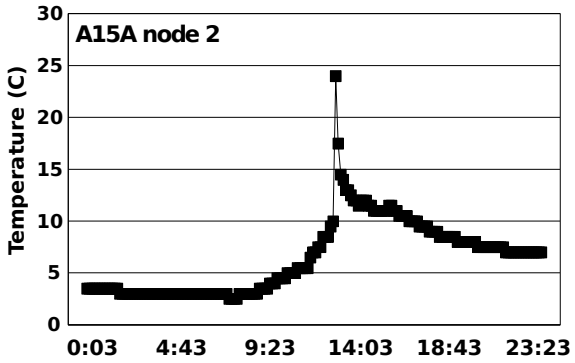
Year 3 (2002)

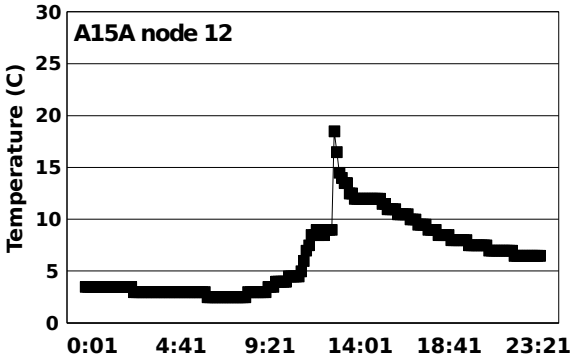
Continued to sample sites and monitor responses to the accelerated/delayed burns.

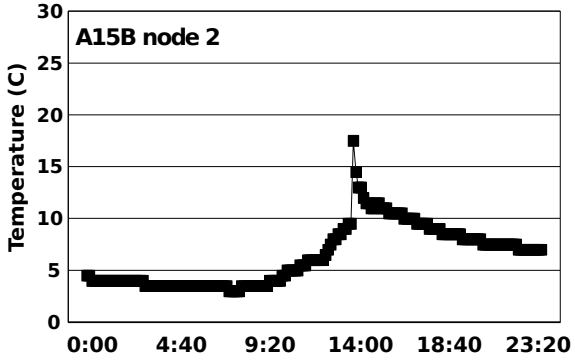
- Acorns placed to census seed predation (2/02)
- **Two-yr burn sites burn (10/01 – 5/02);** several were burned in wildfires.
- Vegetation re-surveyed (6-8/02)
- Environment monitored (1-12/02)
- Field samples collected for biomass and decomposition (1-12/02)
- Field samples collected for biogeochemistry (N, C) (1-12/02)

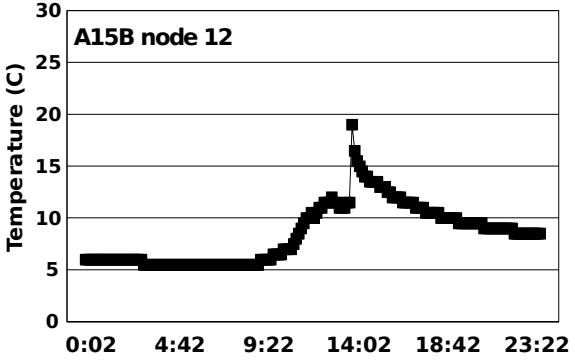
early results – environment

Soil temperature at 1 and 10 cm below ground was logged at minute intervals in burned sites





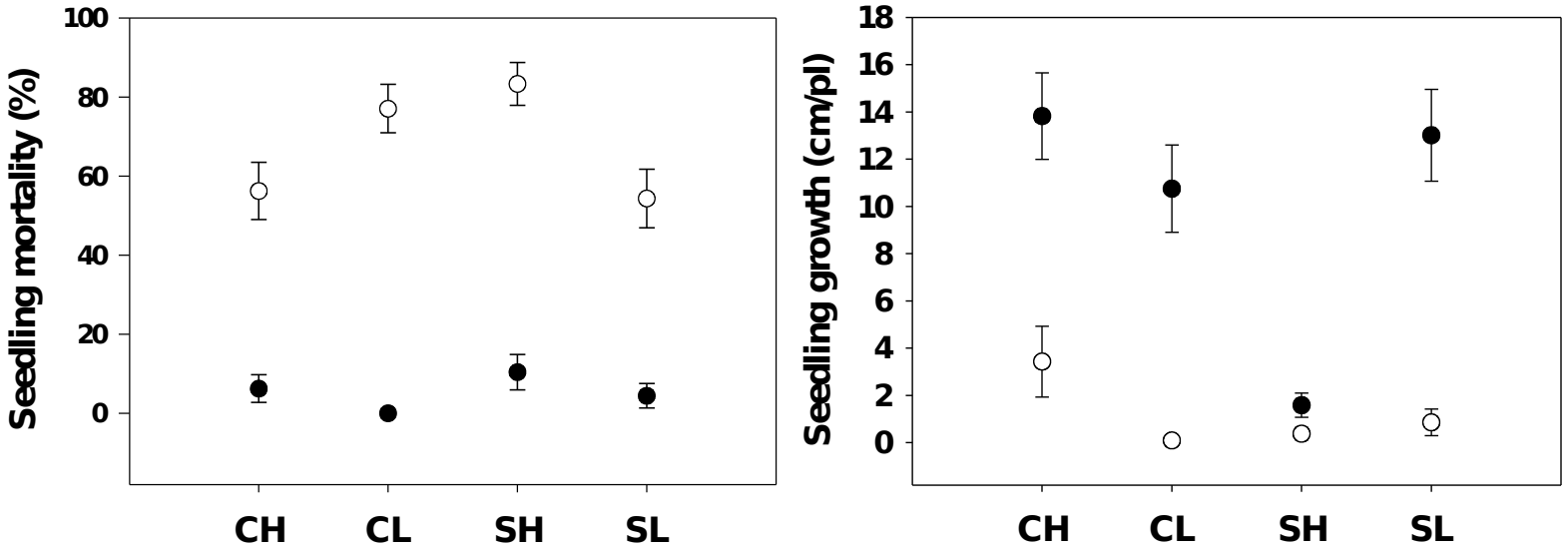




There was a distinct, but modest and relatively short-lived, temperature effect at 1 cm depth as fire moved through a site (two sites shown). This depth is in the region of microbial and root activity. Data for 10 cm depth sensors are still being evaluated, but we anticipate few detectable signals at that depth

early results – regeneration potential

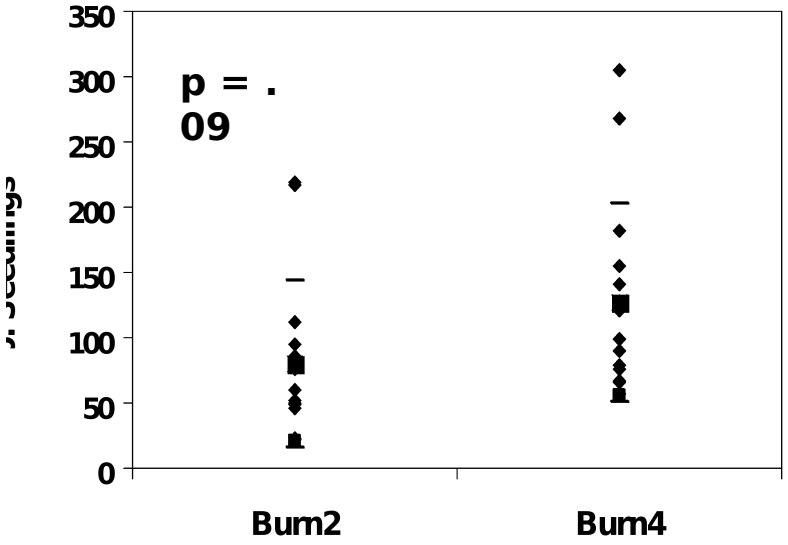
Regeneration, which includes seed survival and establishment via seedlings or sprouts, is a metric of ecosystem sustainability. As part of a set of procedures to assess regeneration potential, white oak and longleaf pine seedlings were planted in 4-yr burn sites in February, 2001. Initial survival and growth were determined in June 2001.



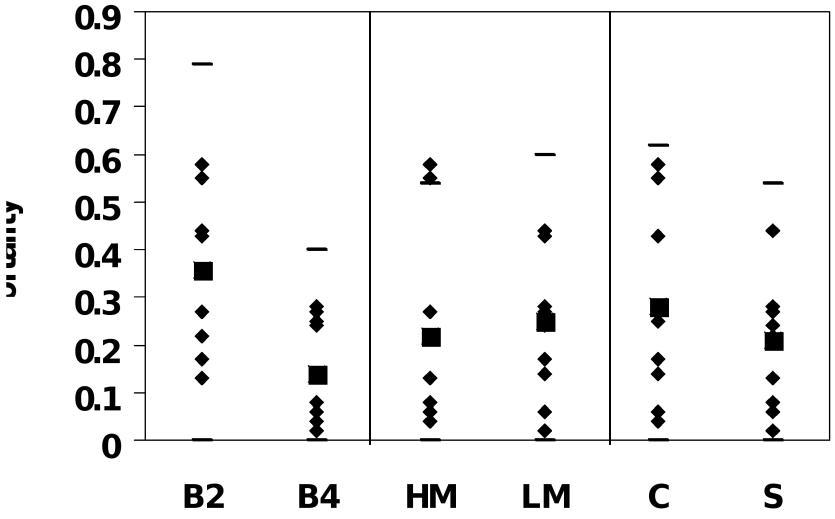
Over the first 9 weeks, oak seedlings (filled circles) had lower mortality and higher growth rates (means + 1 std error shown) than pine seedlings in clayey (C) and sandy (S) sites with heavier (H) or lighter (L) military training. Seedling growth and mortality will be monitored through 2004.

early results – regeneration potential

Naturally established seedlings/sprouts were censused in each site in 2001 and 2002. Up to 125 oak and 125 pine seedlings/sprouts were tagged in each site in 2001 and censused for mortality in 2002.



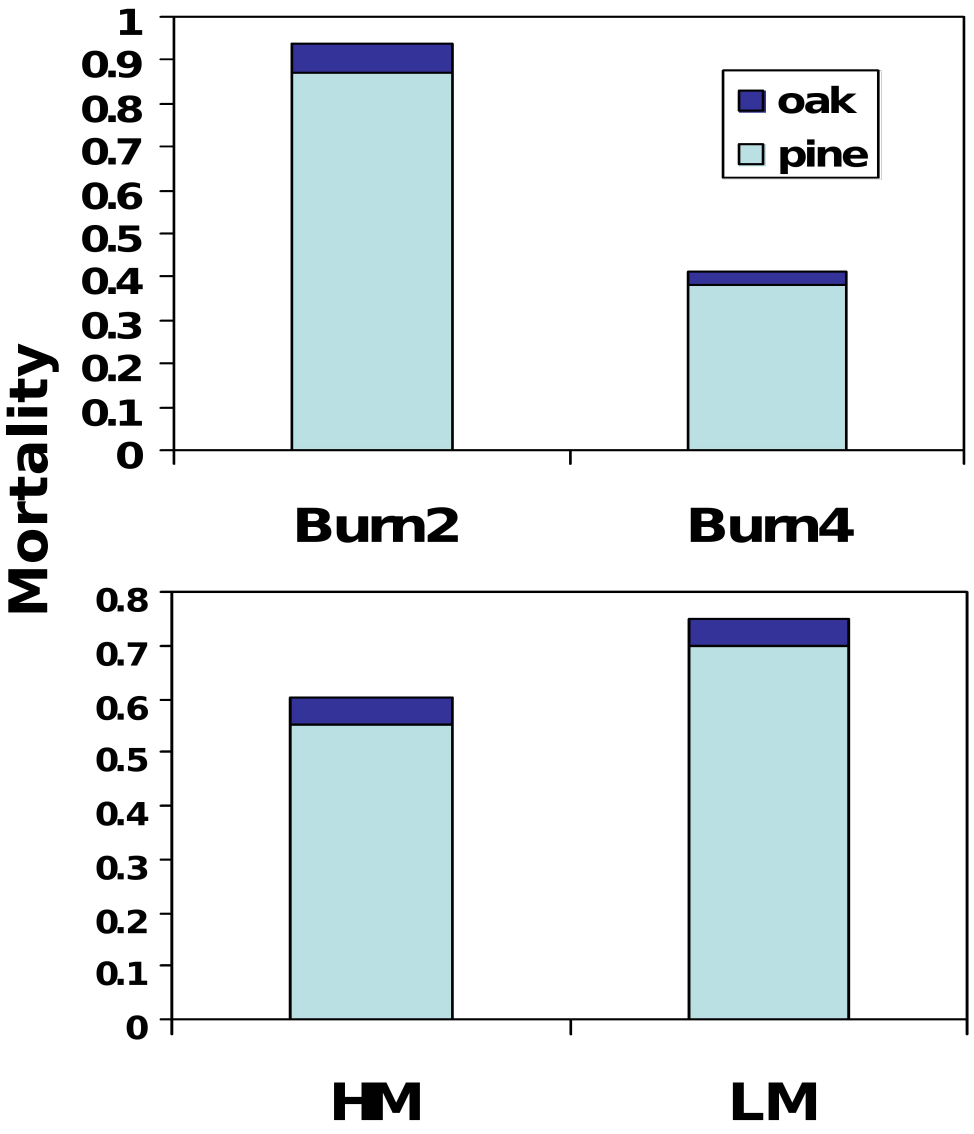
Mortality (oak and longleaf combined) of tagged seedlings/sprouts was greater in 2-yr burn (B2) than 4-yr burn (B4) sites ($p < .0001$), lower (LM) than higher (HM) military use sites ($p = .007$), and clay (C) than sandy (S) sites (.03).



There were more seedlings/sprouts in 4-yr burn sites than in 2-yr burn sites in 2002. The proportion of pine, oak, or other hardwood species did not differ between burn treatments, high and low military use sites, or soil types.

Graphs show mean and standard deviation of each category and mean of each site within the category

early results – regeneration potential

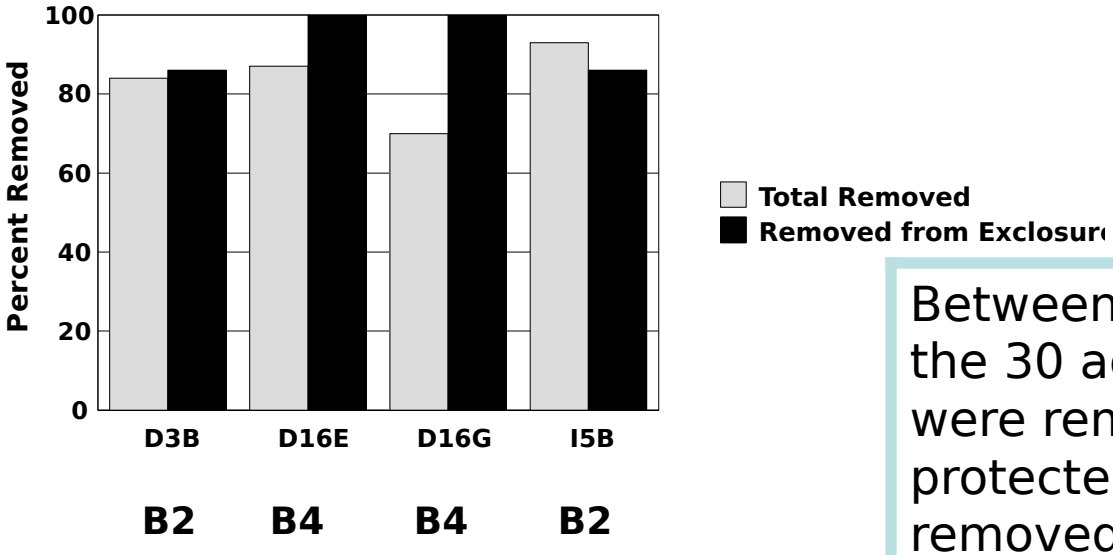


The greater mortality of naturally occurring seedlings/sprouts in 2-yr burn sites was primarily due to pine (all species combined) seedling mortality.

- Mortality of pine seedlings tagged in 2001 and censused in 2002 after the fire treatment ranged from 0 to 91% among sites and was greater both in 2-yr burn compared to 4-yr burn sites ($p < 0.0001$) and in lighter compared to heavier military use sites ($p = 0.06$),
- Mortality of tagged oak seedlings/sprouts was low (0 – 20%) and did not differ between burn treatments ($p = 0.14$) or military use

early results – regeneration potential

To assess the effect of seed removal by seed predators on regeneration potential, southern red oak (*Quercus falcata*) acorns were placed in two burned and two unburned sites. Half the acorns in each site were "protected" from predation by larger mammals by wire mesh exclosures that included a small door to allow small mammal access. Acorn removal was checked four times.



Between 75 % and 95 % of the 30 acorns in each site were removed, and all the protected acorns were removed in the two unburned sites.

early conclusions – regeneration potential

- acorn removal is high in both burned and unburned sites, suggesting that seed density could limit recruitment in low seed years
- burning reduces the number of naturally established seedlings/sprouts
- mortality of naturally established seedlings/sprouts varied from < 10 % to > 50 % among sites, and was greater
  - in burned compared to unburned sites
  - in lighter compared to heavier military use sites
  - in clayey compared to sandy soils
- greater seedling/sprout mortality in 2-yr compared to 4-yr burn sites and heavier compared to lighter military use sites was primarily due to pine seedling mortality
- initial mortality of planted pine seedlings was greater than that of planted oak seedlings

➢ Low establishment could limit regeneration, especially of pines.

➢ Are frequently burned sites not sustainable if regeneration is from seeds?

➢ Does greater seedling/sprout mortality, which was likely due in part to drought, in lighter military use and clayey soil sites indicate a lower threshold of sustainability in these sites if regeneration is from seeds/sprouts?

procedures - biomass and decomposition

Fire can remove biomass and alter decomposition. We have established a set of procedures to compare biomass and decomposition between the burn treatments and among land use categories.

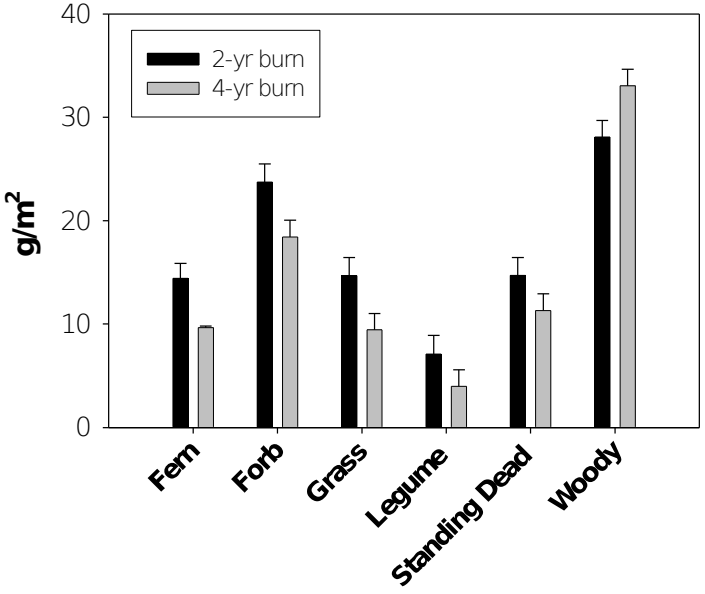
- Litter/seed fall traps – measure biomass input in 32 sites
- Pooled organic layer harvests from 32 sites May 01,02; pooled O layers also were harvested before and after the burns
- Aboveground longleaf litter decomposition bags with elevated litter component-16 sites
- Sampling 16 sites for ground layer biomass in 7-8/02 (Drake)
- Aboveground mixed deciduous litter decomposition experiment deployed 9/02- 8 sites
- Root decomposition experiment using vertical litterbags (8 sites) installed in the soil deployed 6/02 and the first sample was collected 7/02 – experiment will run 1yr
- Root ingrowth experiment (8 sites) installed 6/02 to measure root production, the first samples were collected 7/02
- Soil respiration monitored quarterly on 4 sites of varying soil texture

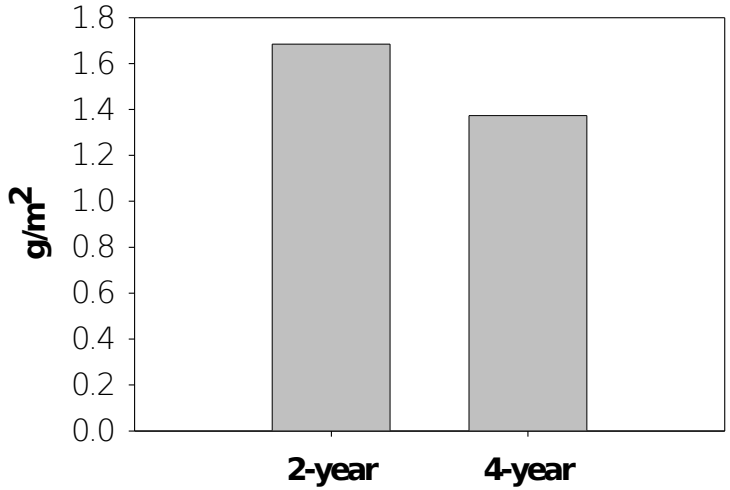
early results – ground layer biomass (Drake)

Fire removes plant biomass and has been shown to affect the relative proportion of nitrogen-fixing legumes in ground layer vegetation. Sara Drake, a UGA graduate student, is comparing plant biomass, relative importance of legumes, and density of nitrogen-fixing legume root nodules between 2-yr and 4-yr burn sites.

- To sample vegetation, two 0.85 m^2-circular plots were placed adjacent to each of 12 points along transects. Aboveground vegetation was clipped at ground level and sorted into categories (legumes, forbs, grasses, woody plants <1cm stem diameter, ferns, and standing dead). Vegetation was clipped in July and early August 2002 because peak biomass of herbaceous plants occurs during this time. Plants were dried to constant mass at 70º C and weighed. Dry plants will be ground in a Wiley ball mill and analyzed on a mass spectrometer for C and N content.
- A five cm diameter soil core was be taken at a 16 cm-depth within each circular quadrat. Roots and root nodules were removed from the soil by hand and washed with water over a 2 mm sieve. Root mass will be determined by first drying the roots at 70ºC for 24 hours and weighing them. Root nodules were counted and weighed as well.

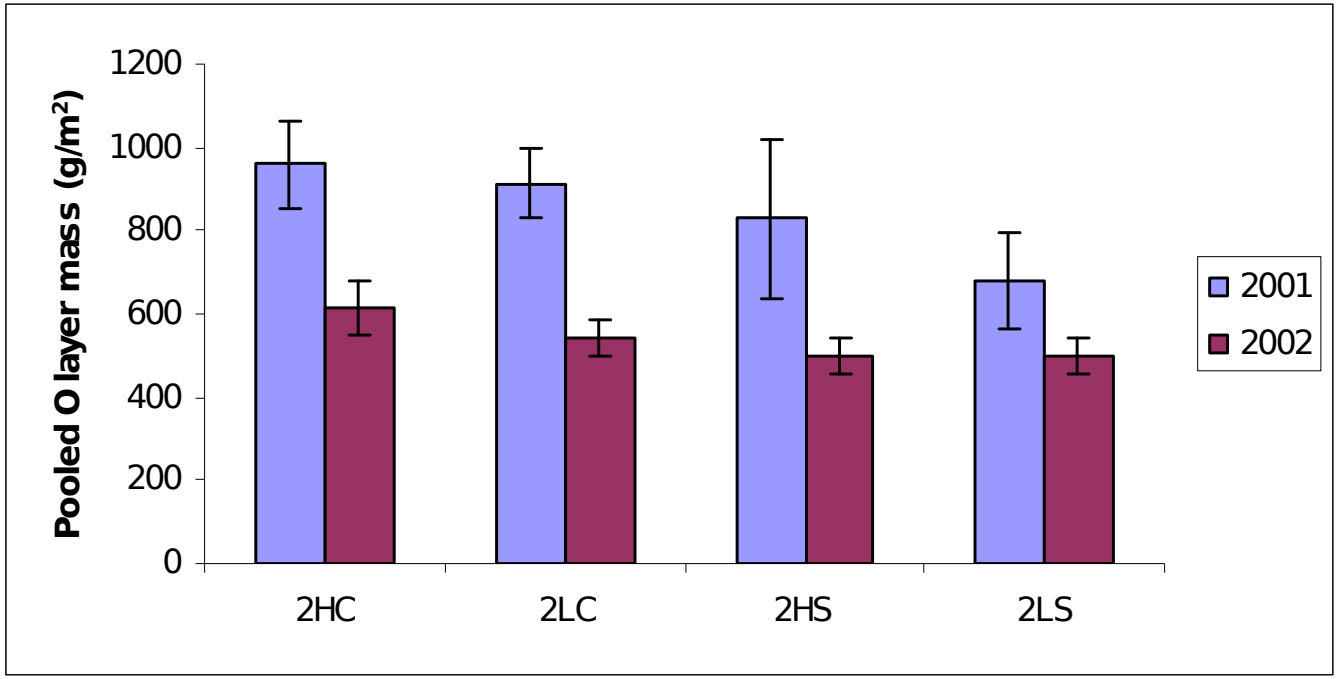
early results – ground layer biomass





- fire causes a decrease in biomass of woody species, but an increase in fern, forb, grass, and legume biomass.
- fire removes woody species, including woody seedlings that likely collect in intervals between fires
- fire also causes an increase in root biomass, which agrees with the trend for aboveground herbaceous vegetation

early results – organic layer mass



Organic layer loss due to prescribed burns on the 16 2-yr burn sites. Sites with greatest pooled organic layer in 2001 lost the most mass to combustion.

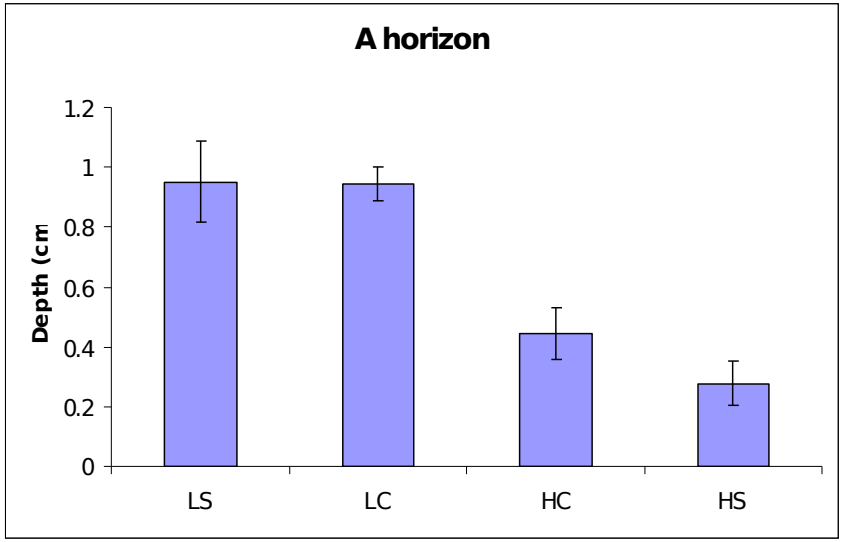
procedures – nitrogen dynamics

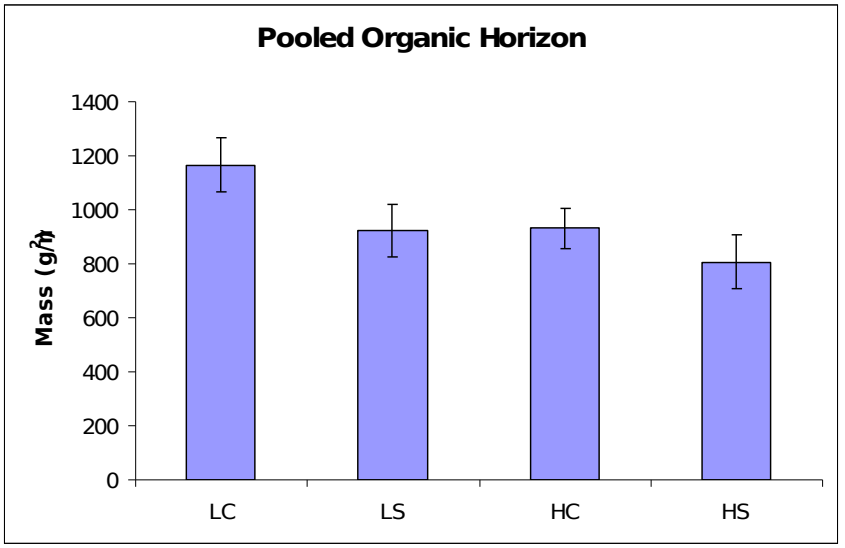
- Litter/seed fall traps measure N input from litter in 32 sites
- N in organic layer harvests from 32 sites 5/01,02, pre and post burn
- Soil laboratory N mineralization incubations (Methods shared with Garten) to measure N availability across sites; 01, 02
- Field mineralization study 01,02
- Pre and post burn soil samples for NH_4 and NO_3; 02
- Aboveground longleaf and mixed deciduous litter decomposition bags with elevated litter component to measure nitrogen loss and/or immobilization; 9/02
- Root decomposition experiment using vertical litterbags to measure nitrogen loss and/or immobilization installed in the soil deployed 6/02 and the first sample was collected 7/02 – experiment will run 1yr
- Plant root simulator probes 4 sites to measure N uptake in situ
- Lysimeters measure N flux from system

early results – nitrogen dynamics

Metrics related to soil nitrogen availability and biogeochemical cycling were assessed among the sites before and after the 2-yr burn.

preburn results



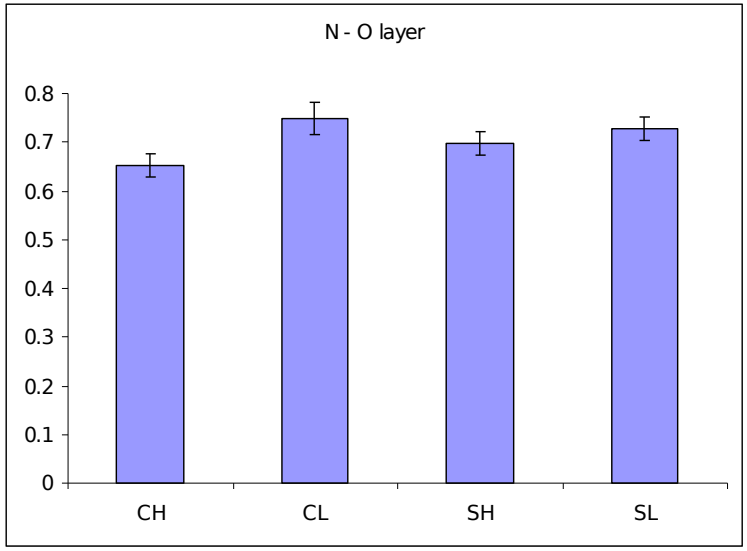


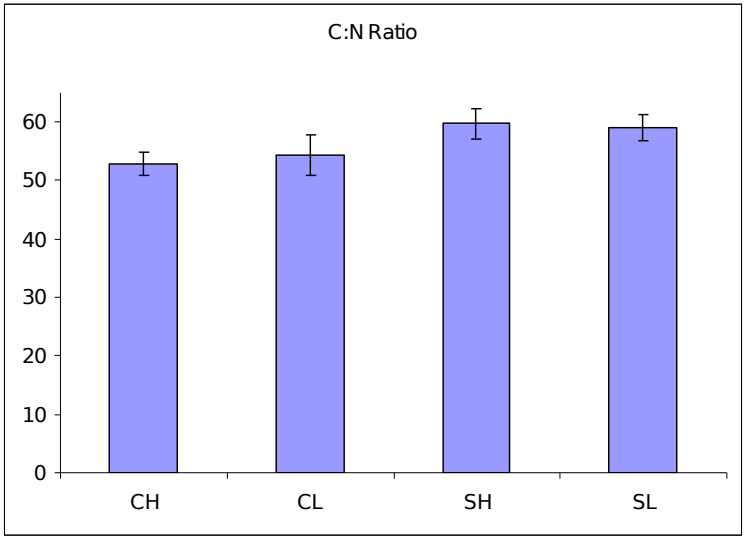
Deeper A horizon (cm) in sandy and clayey sites with lighter military use possibly reflects less erosion or compaction on these sites.

Organic layer dry mass (g/m^2) was greatest in low military use sites with clayey soil. These sites also have the highest canopy tree density.

early results – nitrogen dynamics

preburn results





Nitrogen content (%) of the O layer was greatest on sandy and clayey sites with lighter military use.

Carbon/nitrogen ratios were highest in sites with sandy soils, indicating lowest quality litter on these sites.

early results – nitrogen dynamics

preburn results

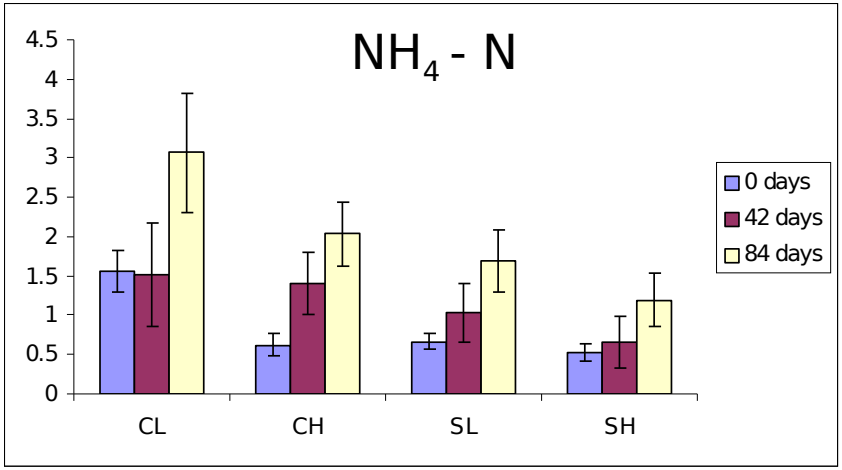
Plant root simulator (PRS) probes were installed and left in place for 14 days in four heavier military use sites (two with clayey soil and two with sandy soil) to assess nitrogen availability to plants.

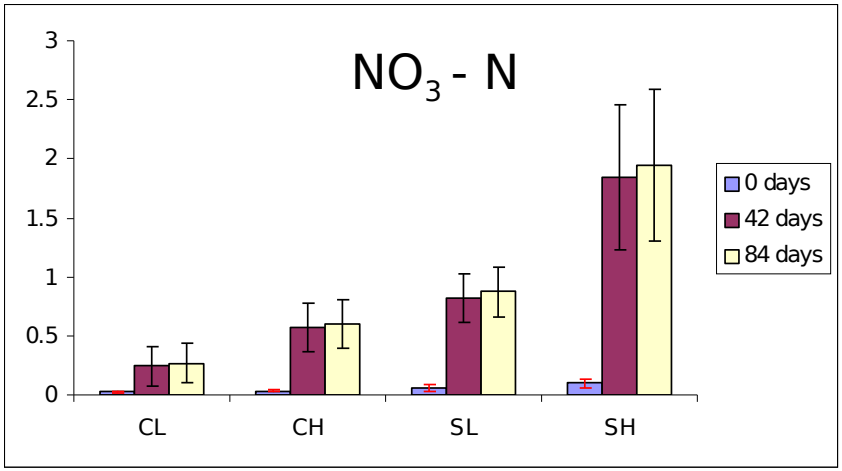
Site	Trt	O layer mass (g/m^2)	O layer C:N	O layer % N	% clay	PRS probes NH_4	PRS probes NO_3
D14A	HS	1605	35	.876	4.6	2.61 (0.90)	9.54 (2.32)
F1C	HS	906	55.8	.739	7.4	2.25 (1.09)	0.57 (0.20)
D16F	HC	944	53.9	.688	27.2	0.62 (0.37)	0.19 (0.09)
D16H	HC	787	52.1	.653	19.2	0.95 (0.56)	0.39 (0.08)

More nitrogen (µg N/10 cm^2/14 days) is available to plants, particularly as ammonium, in sites with sandy soil. This could relate to the greater N capital on these sites, as illustrated by the greater % N in the organic layer.

early results – nitrogen dynamics

preburn results

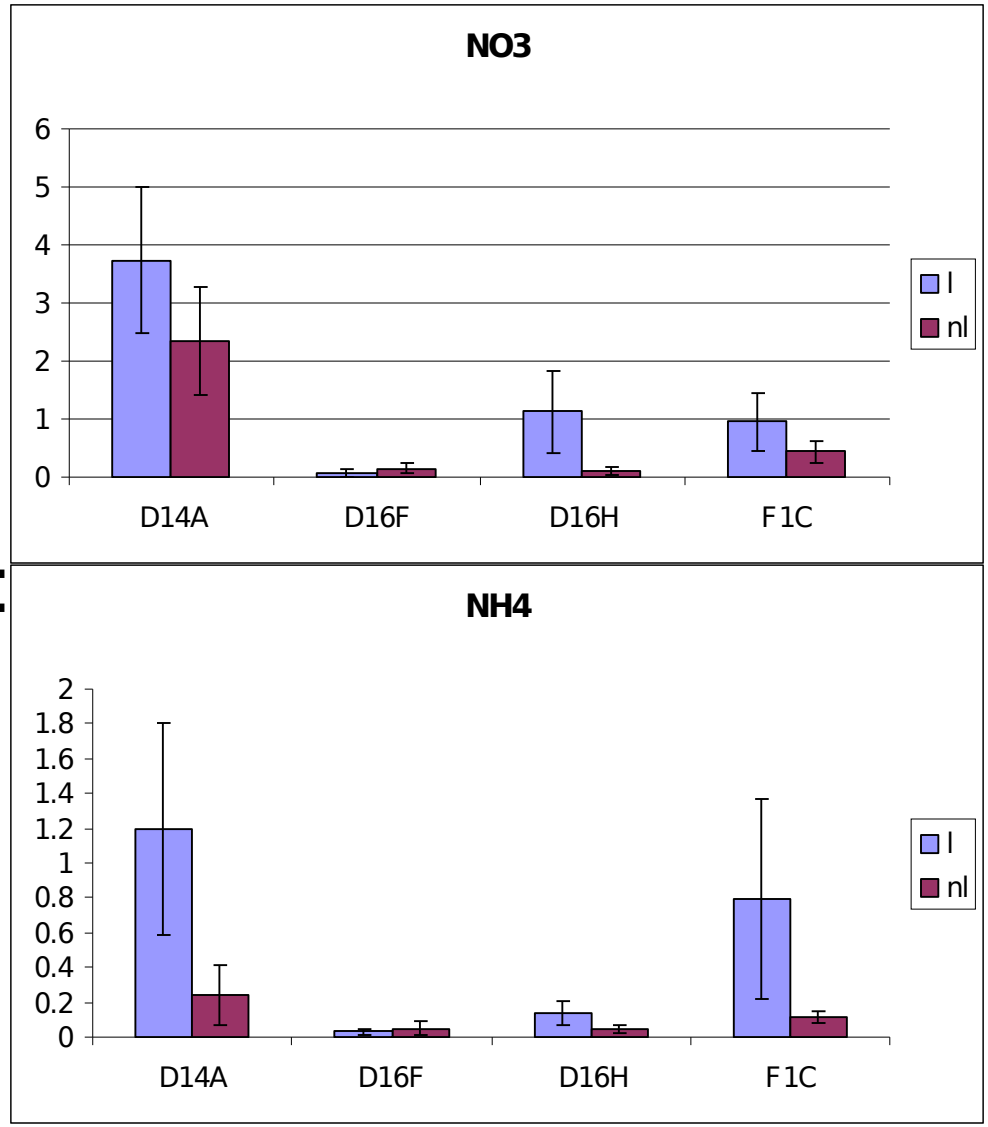




Laboratory soil mineralization incubations of samples (9/site) taken from all sites showed opposite patterns among the military use/soil texture categories. Extractable NH_4-N (µg N/g soil) was greater in sites with clayey soil and lighter military use (CL), while NO_3-N was greater in sites with sandy soils and heavier military use (SH).

early results – nitrogen dynamics

preburn results



To test effects of 1) O layer removal on the supply of N to mineral soil and 2) complete loss of the pooled O layer on N flux through the soil, lysimeter pots were installed in two heavier military use sites with sandy soil and two with clayey soil.

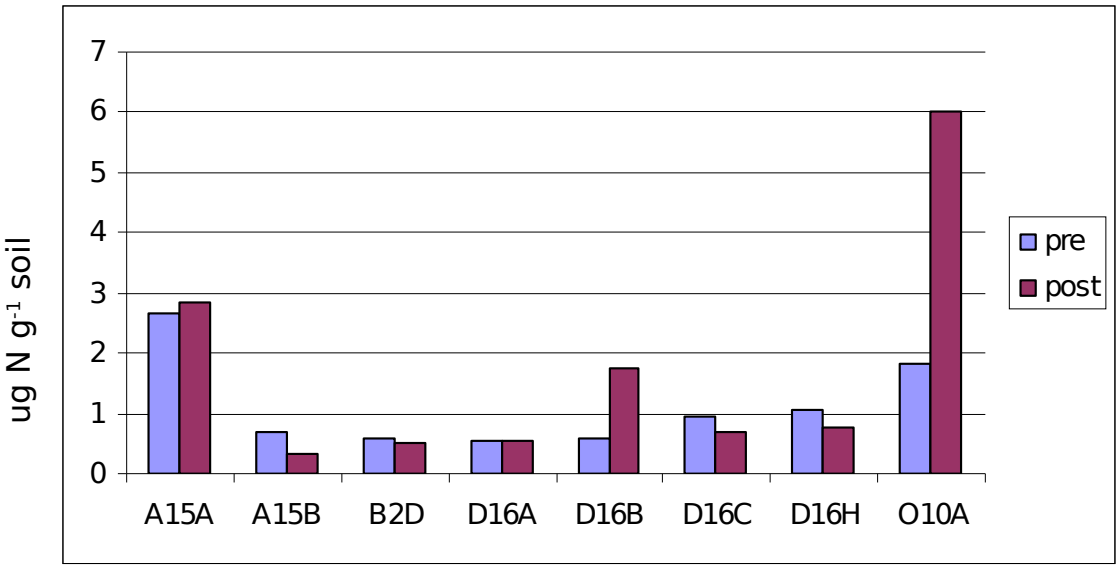
Sites with sandy soil (D14A, F1C) had highest N loses. Removing the O layer lowers the supply of NO_3 leaching through the soil by 50 % and greatly reduces NH_4 transport through the soil column. These results suggest sandy soils may be less buffered for disturbances that remove the litter

early conclusions – preburn nitrogen dynamics

- NH_4 production is generally thought to control nitrification.
  - Clayey sites tended to produce greater quantities of NH_4, which may be bound by clays and less available to plants or microbes. Lower NH_4 uptake rates by PRS probes in sandy soils support this idea.
  - In contrast to NH_4, NO_3 production was greatest in sandy sites. Greater NO3 production could buffer disturbance effects on sandy sites or could lead to greater losses via leaching.
- Lysimeter pot results indicate greater leaching of both NO_3 and NH_4 from sandy soils. These sites also may show more immediate and drastic nitrogen loss in response to disturbances that remove the litter layer.
- Our results do not support the paradigm that greater soil N yields greater productivity. The higher NO_3 production on sandy sites does not translate to more productive, higher quality vegetation.
- Do sites with sandy soil have a higher threshold of response to land use disturbances because something other than N availability (e.g. plant

early results – nitrogen dynamics

burn effects



- Immediate extractable N from mineral soil following burns.
  - Samples did not include organic layer or a- horizon
  - In general, extractable NH_4+ NO_3 was either unchanged or more available following prescribed burns. These samples are waiting to be analyzed for total C H N analysis. That, plus analysis of the 2002 soil data, will add to our understanding of longer term nitrogen dynamics with these prescribed burns.

early conclusions – fire effects

- fire has an immediate, short-term effect on soil temperature at 1 cm
- Extractable ammonium and nitrate were either unchanged or more available after fire
- fire causes an increase in aboveground biomass of non-woody vegetation, but removes woody biomass, including tree seedlings that may accumulate between burns
- fire results in organic layer loss roughly in proportion to pre-fire condition
- fire reduces the number of naturally established seedlings/sprouts, especially pine s

early conclusions – thresholds associated with land use at Fort Benning

- Initial site conditions suggest
  - pine (longleaf) canopy is sustainable with heavier military use or frequent (< 3 yr) burns
  - more frequent burning (< 2 yr) promotes open-site, successional understory with little regeneration of canopy species, and may be beyond the threshold of sustainability
  - sites with sandy soil have greater nitrate production, but this does not translate to more productive vegetation. Compared to clayey sites, sandy sites may show more immediate and drastic N loss in response to disturbances, but may have a higher threshold of sustainability because other factors such as plant uptake drive vegetation response.

early conclusions – thresholds associated with land use at Fort Benning

- Initial comparisons between the 2-yr and 4-yr burn sites suggest
  - a single prescribed burn does not cause a drastic or prolonged change in soil temperature or extractable mineral soil N. This suggests that fire would be sustainable with respect to these environmental drivers
  - seed density, due to acorn removal, could limit oak recruitment in burned and unburned sites. However, higher mortality, especially of pine seedlings, after burning, and accumulation of woody biomass between burns, suggest frequent burning is not sustainable if regeneration is from seeds
  - fire removes above ground woody biomass and the organic layer roughly in proportion to the pre-fire mass. Frequent burning could eventually result in unsustainable woody biomass and potential regeneration loss, especially on low-productivity sites, if woody species do not recover or